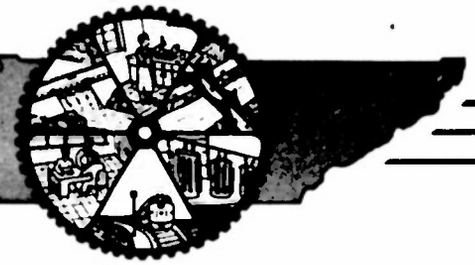


# THE UNIVERSITY OF TENNESSEE
## DEPARTMENT OF ELECTRICAL ENGINEERING

# DEVELOPMENT OF A HIGH FREQUENCY STEERABLE ANTENNA



Navy Department
Bureau of Ships
Electronics Divisions

Interim Development
Report No. 8

Contract No. NObsr-57448
Index No. NE-091035 ST7
10 May 1953

A PROJECT OF THE ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE COLLEGE OF ENGINEERING
Knoxville 16, Tennessee

~~RESTRICTED~~

# INTERIM DEVELOPMENT REPORT
# FOR
# DEVELOPMENT OF A HIGH FREQUENCY STEERABLE ANTENNA

This report covers the period
1 April 1953 to 30 April 1953

ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE
KNOXVILLE, TENNESSEE

Navy Department — Bureau of Ships
Electronics Divisions

Contract No. NObsr-57448 — Index No. NE-091035 ST7
10 May 1953



Copy No. 6

~~RESTRICTED~~

[redacted]

## ABSTRACT

This report covers work done on Contract No. NObsr-57448, Index No. NE-091035 ST7, at The University of Tennessee during the month of April 1953.

The following was accomplished:

1. The development of the physical facilities of the antenna test site was completed. The installation of instruments may now be made.

2. Maximum usable frequencies were determined, as a function of time of day, for transmitters located at Port Lyautey, Seattle, and Adak. The path lengths considered were 800, 1200, 3200 and 8000 kilometers and ionospheric data for June 1947 and January 1953 were used. A start was made in using these data for determining the necessary characteristics of the antenna.

3. Efforts were continued to obtain reliable angle-of-arrival data.

4. Work was continued on the problem of horizontal steering of the beam of a rhombic antenna. The numerical calculations have proven to be very involved and no results are yet available on the scheme being tried.

5. An investigation has been started of the possibility of improving the performance of square rhombic antennas by increasing the phase velocity along the conductors of the antenna. The results obtained to date are shown in Figures 5 to 7, inclusive.

6. All pertinent literature on V-antennas and on tilted antennas has been read as a first step in the investigation of the possibilities of using inclined radial wires as an antenna suitable for the present task.

7. Work was started on the analysis of the propagation characteristics of a circular travelling-wave antenna.

8. A circular array for which the horizontal pattern is invariant with frequency was investigated.

[redacted]

# PART I

## Purpose

This project involves the development of a high frequency steerable antenna having the following characteristics:

1. It shall be operable throughout the frequency range of 4 to 32 megacycles per second.

2. It shall be capable of four, or more, simultaneous transmissions on different frequencies, and at different azimuth and elevation angles.

3. For each transmission, it shall be capable of being directed to any azimuth angle and to any elevation angle between the horizon and $30^{o}$ above the horizon.

The communication system shall provide reliable 24-hour day-to-day communication with a 20-decibel signal-to-noise ratio. The ranges to be covered are from approximately 500 nautical miles to 4000 nautical miles.

The development consists of two phases:

Phase I. Theoretical and experimental studies.

Phase II. Development of design criteria.

[redacted]

General Factual Data

Personnel:

| | | | |
|---|---|---|---|
| F. V. Schultz | Project Director | 96 | Man-hours |
| W. D. Leffell* | Assistant Engineer | 3 | Man-hours |
| J. D. Tillman | Assistant Engineer | 8 | Man-hours |
| L. W. Ricketts* | Junior Engineer | 40 1/2 | Man-hours |
| H. P. Neff | Junior Engineer | 176 | Man-hours |
| G. R. Turner | Secy-Draftsman | 84 1/2 | Man-hours |
| L. Phillips* | Technician | 80 | Man-hours |
| C. E. Blakely | Student Computer | 15 | Man-hours |
| T. E. Lassiter | Student Computer | 10 | Man-hours |
| D. Marcum | Student Computer | 54 1/2 | Man-hours |
| H. Knox | Student Computer | 139 1/2 | Man-hours |
| D. J. Smith | Typist | 4 1/2 | Man-hours |
| A. Rich | Multilith Operator | 3 | Man-hours |

* Preparation of antenna test facility.

[redacted]

References

Baker, W G . "A Chart for Rhombic Antenna Design," A. W. A. Technical Review, Amalgamated Wireless Australasia, 554 Parramatta Road, Sydney. 6:177, 1944.

Barker, R. H., "Rhombic Aerial Design Chart," Wireless Engineer, Dorset House, Stamford Street, London S. E. 1. 25:361, November 1948.

Bruce, E. and Beck, A.C., "Experiments with Directivity Steering for Fading Reduction," Bell System Technical Journal, Vol. 14, p. 195, April 1935.

Bruce, E., Beck, A.C., and Lowry, L.R., "Horizontal Rhombic Antennas," Proceedings of the Institute of Radio Engineers, Vol. 23, p. 24, January 1935.

Cafferata, H. A., "A Generalized Radiation Formula for Horizontal Rhombic Antennas," Marconi Review, Marconi Instruments, St. Albans, Hertfordshire. Issues 80, 81, and 82. 9(1), January-March, 1946; 9(2), April-June, 1946; 9(3), July-September, 1946.

Carter, P. S., Hansell, C.W., and Lindenblad, N. E., "Development of Directive Transmitting Antennas by R.C.A. Communications, Inc.," Proceedings of the Institute of Radio Engineers, Vol. 19, p. 1773, October 1931.

Christiansen, W. N., "Directional Patterns for Rhombic Antennas," A.W.A. Tech. Review, 7:33, 1946.

Christiansen, W. N., "Rhombic Antenna Arrays," A.W.A. Tech. Review. 7(4)361, 1947.

Christiansen, W.N., Jenvey, W.W., and Carman, R.D., "Radio Frequency Measurements on Rhombic Antennas," A.W.A. Tech. Review 7(2)131, 1946.

Foster, Donald, "Radiation from Rhombic Antennas," Proceedings of the Institute of Radio Engineers, Vol. 25, p. 1327, October 1937.

Friis, H. T., Feldman, C.B., and Sharpless, W.M., "Determination of the Direction of Arrival of Short Radio Waves," Proceedings of the Institute of Radio Engineers, Vol. 22, p. 47, January 1934.

Harper, A. E., Rhombic Antenna Design, D. Van Nostrand Co., Inc., New York, 1941.

References - Continued

Harrison, C. W., "Radiation from Vee Antennas," Proceedings of the Institute of Radio Engineers, Vol. 31, p. 362, July 1943.

Harrison, C. E., "The Radiation Field of Long Wires, with Application to Vee Antennas," Journal of Applied Physics, Vol. 14, p. 537, October 1943.

"Ionospheric Radio Propagation," U.S. Department of Commerce, National Bureau of Standards Circular No. 462, June 1948, Washington, D. C.

Kraus, J. D., Antennas, McGraw-Hill Book Co., Inc., New York, 1950, Chapter 2.

Lewin, L., "Rhombic Transmitting Aerial," Wireless Engineer, May, 1941.

Williams, H. P., Antenna Theory and Design, Pitman and Sons, Ltd., London, 1950.

Harrison, C. W., Jr., "The Inclined Rhombic Antenna," Proceedings of the Institute of Radio Engineers, Vol. 30, p. 241, May 1942.

Detail Factual Data

1. The power line installation at the antenna test facility was completed. The delivery of the antenna pattern recorder has been delayed until after the first of June. All other test equipment is on hand and it is quite likely that experimental work will be started before the recorder is available - the antenna patterns being determined on a point-by-point basis.

2. The maximum usable frequencies (MUF's) have been determined, as a function of time-of-day at the transmitter, for transmitters located at Port Lyautey, Seattle and Adak, and for path lengths of 800, 1200, 3200 and 8000 kilometers north, south, east and west from each transmitter. Ionospheric conditions for June 1947 (sunspot number = 112) and for January 1953 (sunspot number = 30) were used. The results are contained in ninety curves - too many to allow their inclusion in this report. These curves of MUF versus time-of-day are now being used to determine two different operating frequencies to be used each day at each station, for each path length. This latter work has been completed for January 1953 and the results are summarized in Figures 1 and 2.

   It is important to know in the antenna development how the vertical angle of the antenna beam must vary with frequency. In order to obtain a rough preliminary estimate of this required variation, the curves of operating frequency versus path length (Figures 1 and 2 of this report) were used, together with the curves of radiation angle versus path length (Figure 2 of Interim Development Report No. 7). The results are shown in Figures 3 and 4 of this report. Not enough results are available as yet to warrant the drawing of any conclusions.

3. Several organizations have been contacted in an effort to obtain recent and reliable information concerning angles-of-arrival, but nothing new has, as yet, been secured. Full information, however, has not been received from the two most promising sources.

4. The analysis, mentioned in Interim Development Report No. 7, of the method devised for the horizontal steering of the beam of a rhombic antenna has been checked and an error found. Consequently the analysis has had to be redone and no numerical results are yet available. The numerical calculations are very laborious and, therefore, the obtaining of results will be slow. It may turn out that it will be better to investigate this problem experimentally.

Detail Factual Data - Continued

5. At the Bureau of Ships Shore Antenna Symposium, held early in March, Mr. Roland of Pickard-Burns discussed the possibility of altering the characteristics of rhombic antennas by increasing the phase velocity along the conductors of the antenna. On the present project it is desirable to use square rhombics in order to facilitate 360° azimuthal steering of the beam. Such a rhombic has a radiation pattern considerably inferior to that of a well-designed conventional rhombic. Consequently the scheme discussed by Mr. Roland is being investigated in an attempt to improve the performance of a square rhombic. As a first step in this investigation three square rhombic antennas have been designed, having conductor phase velocities of 1.0, 1.2 and 1.414 times the free-space velocity, respectively. Each of these antennas was designed to have, at an elevation angle of 20°, the maximum possible response at this angle. The resulting dimensions and vertical patterns are shown in Figures 5 to 7, inclusive. An examination of these three figures reveals that increasing the phase velocity along the conductor results in an increase in size of the rhombic of optimum design, in a sharpening of the main beam, in a reduction in the magnitude of the side lobes and an increase in gain. These results are to be expected. The practical problem of achieving the desired increase in phase velocity over a wide frequency range has received no serious consideration, as yet.

6. A literature search for material on V-antennas and on tilted antennas has been made and the few pertinent papers read. The next step is to investigate the possibilities of adapting and extending these results to an antenna which will be useful to the present task. The particular antenna which appears to offer some promise of being useful is one made of inclined radial wires, to be used in pairs as terminated V-antennas. The object of the inclination of the wires relative to ground is to circumvent the difficulties arising from the height factor of the antenna when the antenna is used over an 8-to-1 frequency range.

7. Work was started on the analysis of the propagation characteristics of a circular travelling-wave antenna.

8. An investigation was made of a steerable single ring circular antenna array for which the horizontal pattern is invariant with changes in frequency. This characteristic of the pattern was noted in connection with a similar array being studied under Contract No. NObsr-57032, and was investigated to determine its suitability for the present task. The array consists of a group of vertical monopoles arranged in a circle, with a single monopole at the center. The elements around the circumference are excited so that their phase varies uniformly around the circle, there being one complete cycle of phase shift around the ring. The prop-

Factual Data - Continued

erties of the array are as follows:

a. The horizontal pattern is a cardioid.

b. To change the direction of azimuthal pointing only the phase of the current in the central element is varied.

c. The cardioidal horizontal pattern does not vary with frequency if the magnitude of the current in the central element varies with frequency in the proper manner. This variation of the required current in the central element to give a fixed horizontal pattern is shown in Figure 8, for the typical case of an array of 9 elements whose radius is 0.294 wavelength at the highest frequency used.

d. The vertical pattern varies only slightly with frequency if the condition outlined above is satisfied. Vertical patterns are given in Figure 9, for the case described above.

e. If two cycles of phase shift are used the horizontal pattern is a figure -8, which is again invariant with frequency. In general, for n cycles of phase shift, the pattern will consist of n equal and equally spaced lobes.

DEPARTMENT OF ELECTRICAL ENGINEERING
ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE

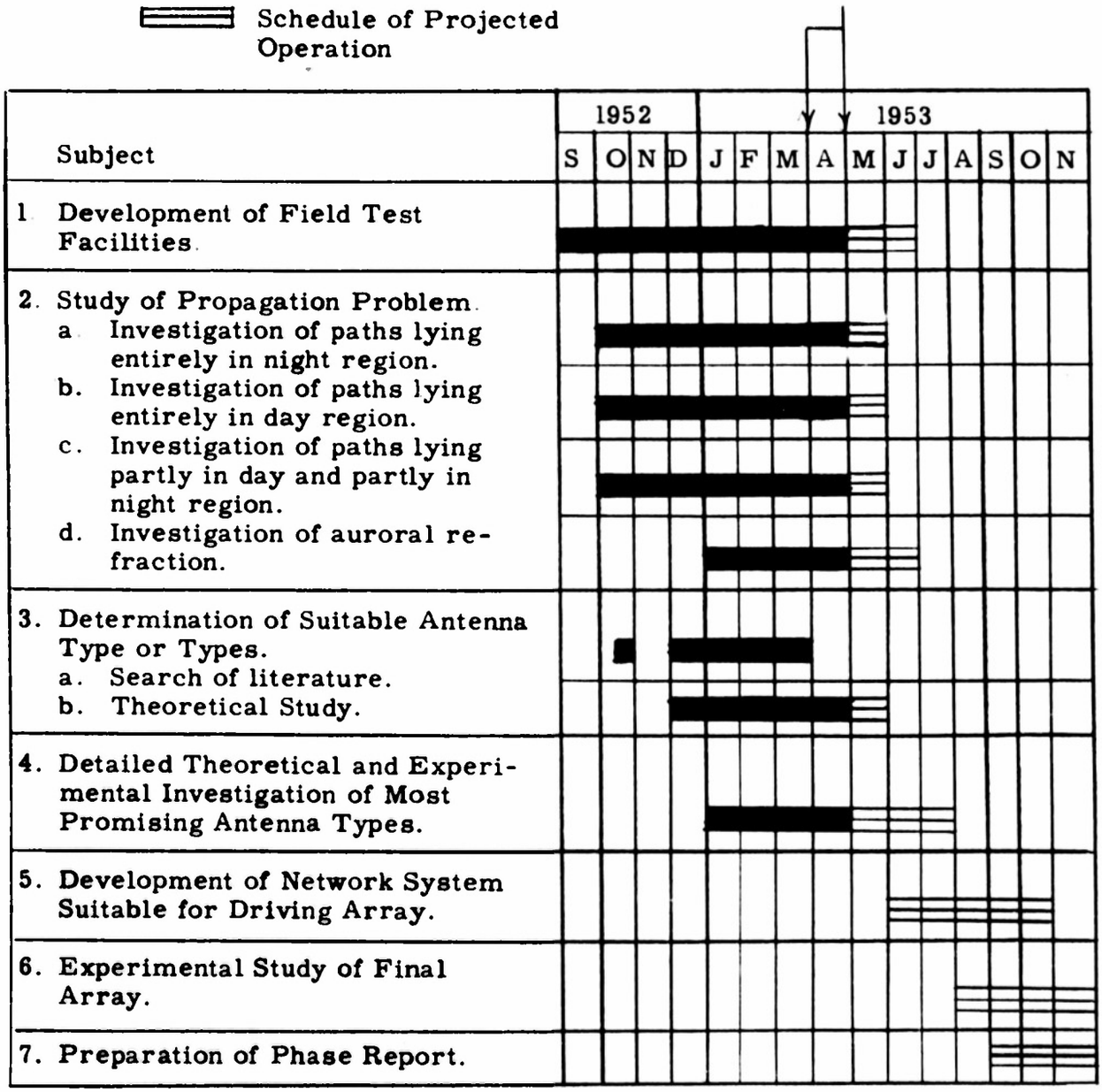
# PROJECT PERFORMANCE AND SCHEDULE

Index No. NE-091035 ST7

Contract No. NObsr-57448 Date: 10 May 1953

Legend: ▬▬ Work Performed Period Covered: 1/4/53 to 30/4/53

═══ Schedule of Projected Operation



## Conclusions

1. The work on the propagation problem has not progressed far enough to allow the drawing of any conclusions.

2. The technique of increasing the phase velocity along the conductors of a rhombic antenna appears to be a valuable tool in the design of rhombic antennas.

3. The patterns of the circular ring array seem unsuitable because of the lack of sufficient directivity. No way of securing a pattern invariant with frequency and having a high enough directivity has yet been found.

Program for Next Interval

During the next month the following work will be pursued:

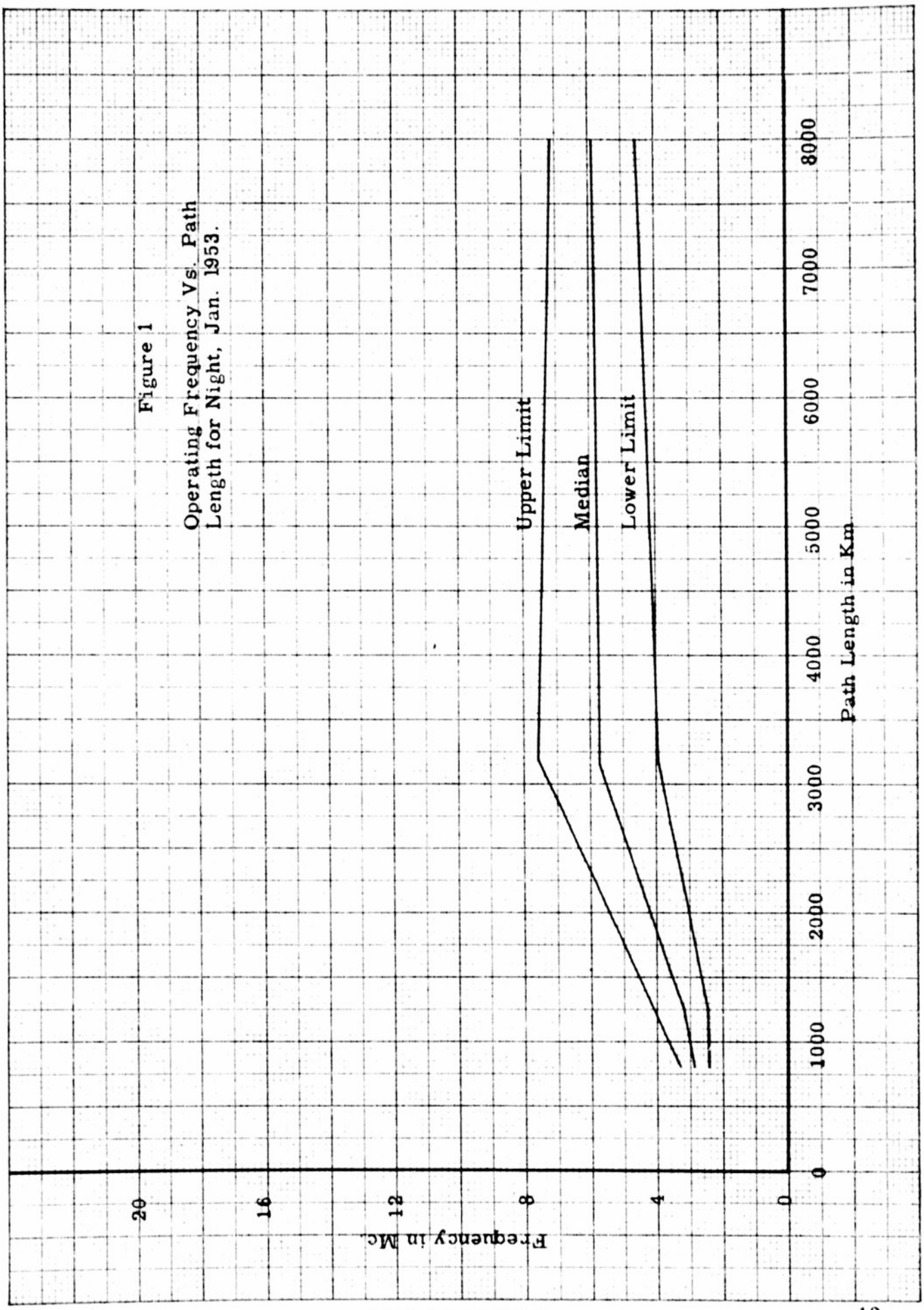
1. Work on the propagation problem will be continued. The determination of operating frequencies for use under ionospheric conditions corresponding to those of June 1947 will be made. The calculation of expected median field intensities, when using these frequencies, will be started. An attempt will be made to adapt this propagation information to the determination of the required characteristics of the antenna.

2. The problem of the horizontal steering of the beam of a rhombic antenna will continue to be investigated.

3. The study of the possiblities of using an antenna consisting of inclined radial wires will be carried on, as will the work on the circular travelling-wave antenna.

Figure 1

Operating Frequency Vs. Path Length for Night, Jan. 1953.



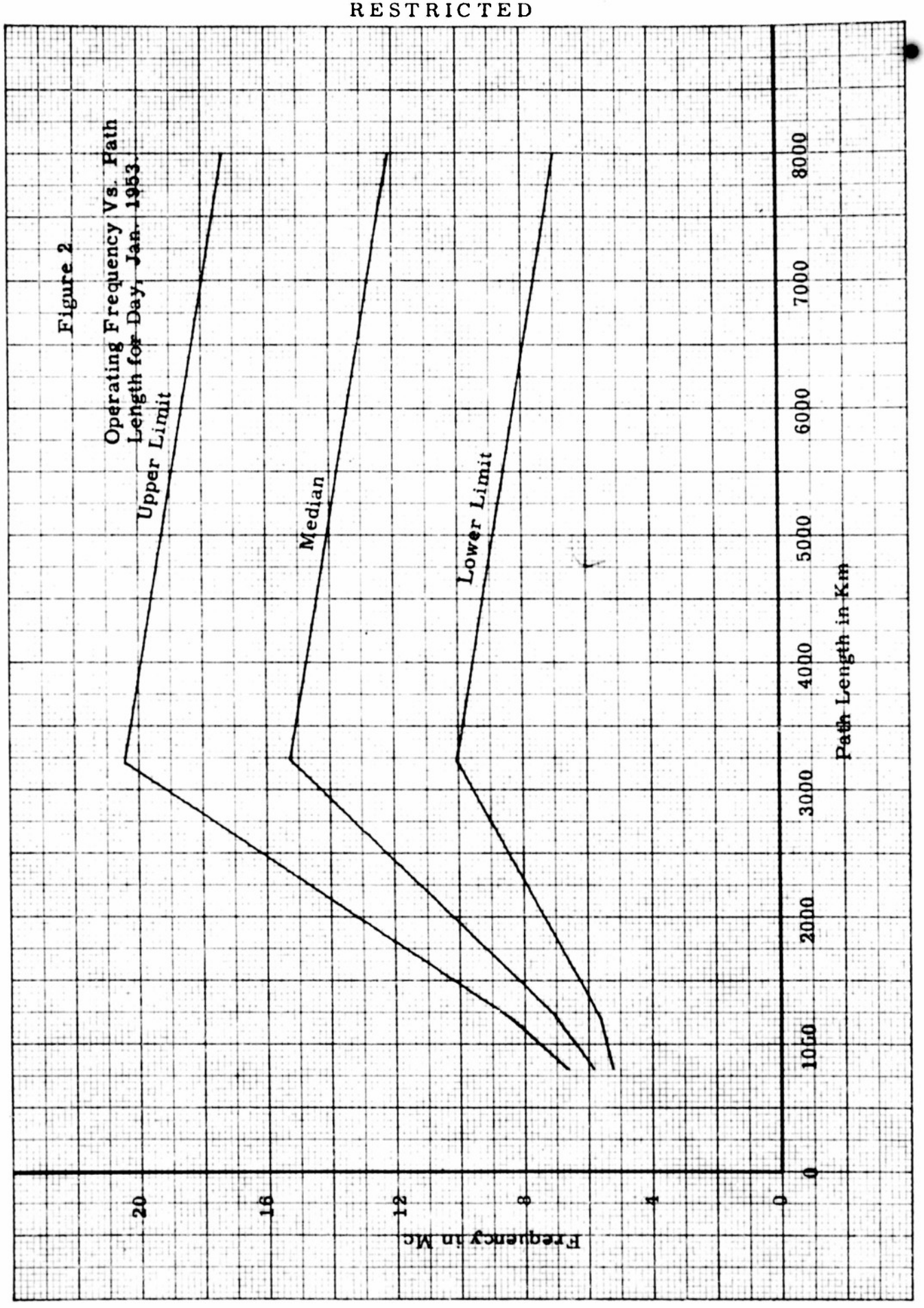

Operating Frequency Vs. Path Length for Day, Jan. 1953.
Upper Limit
Median
Lower Limit
Frequency in Mc
20
16
12
8
4
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Path Length in Km

Figure 2

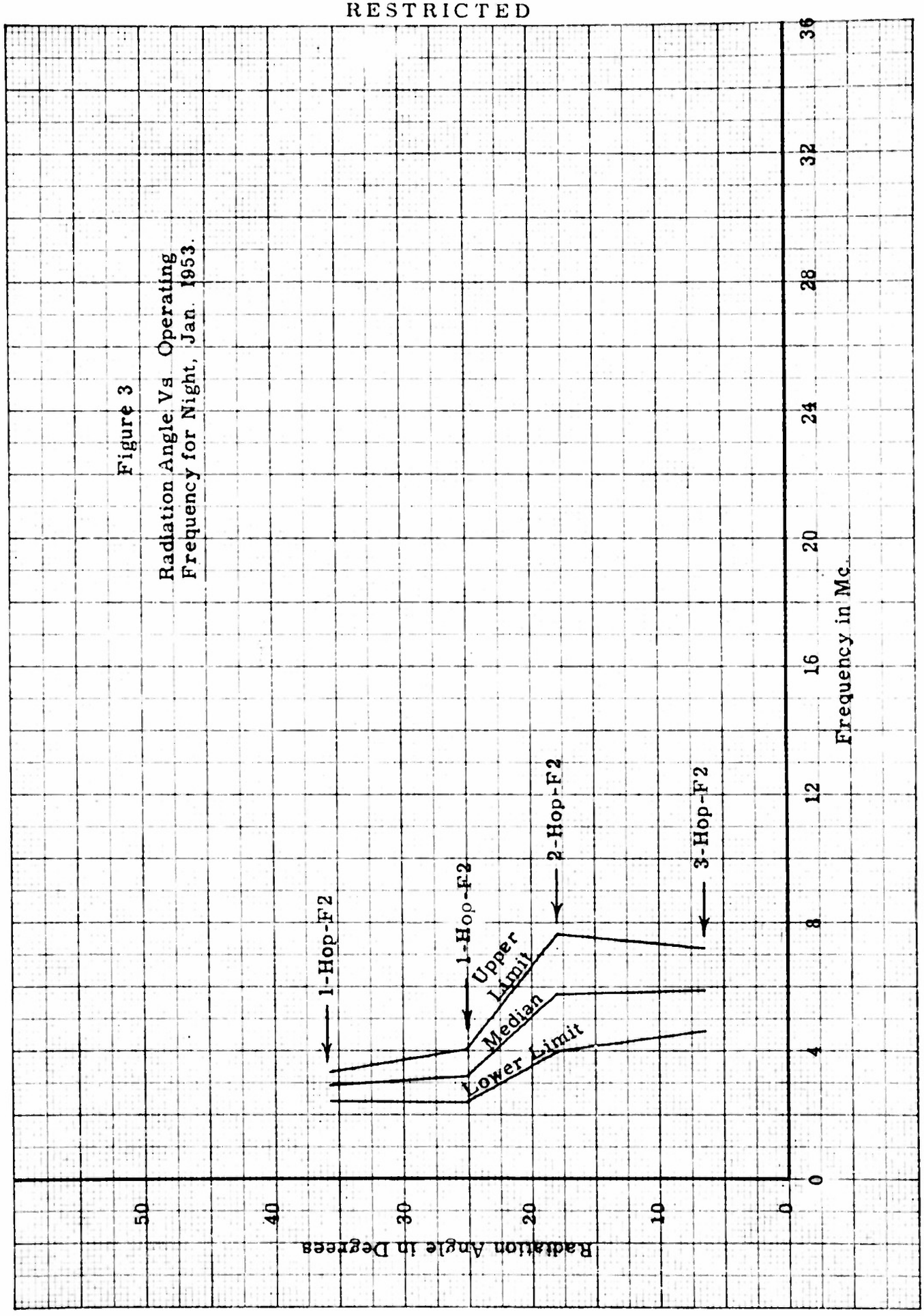



Figure 3

Radiation Angle Vs Operating Frequency for Night, Jan. 1953.

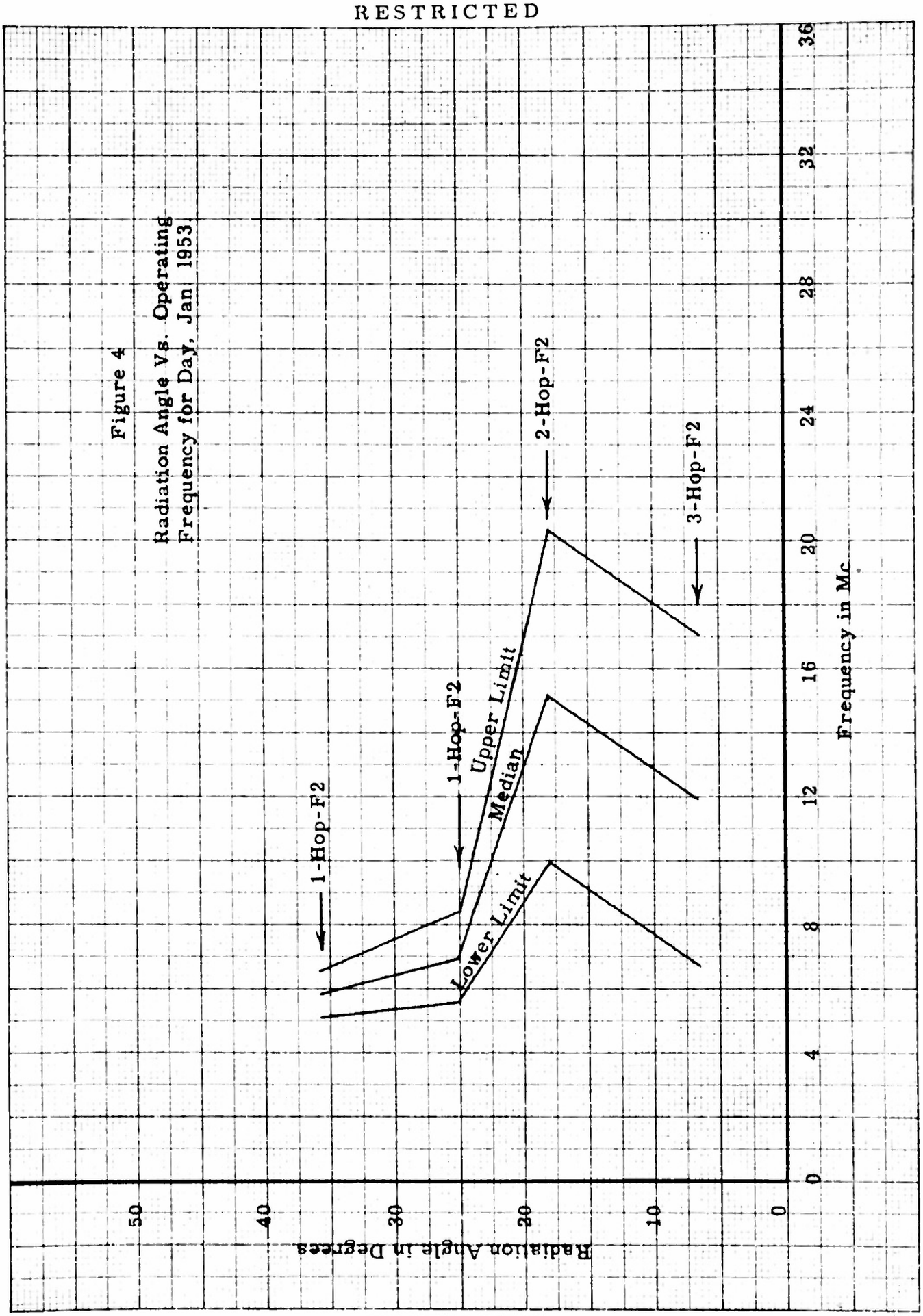


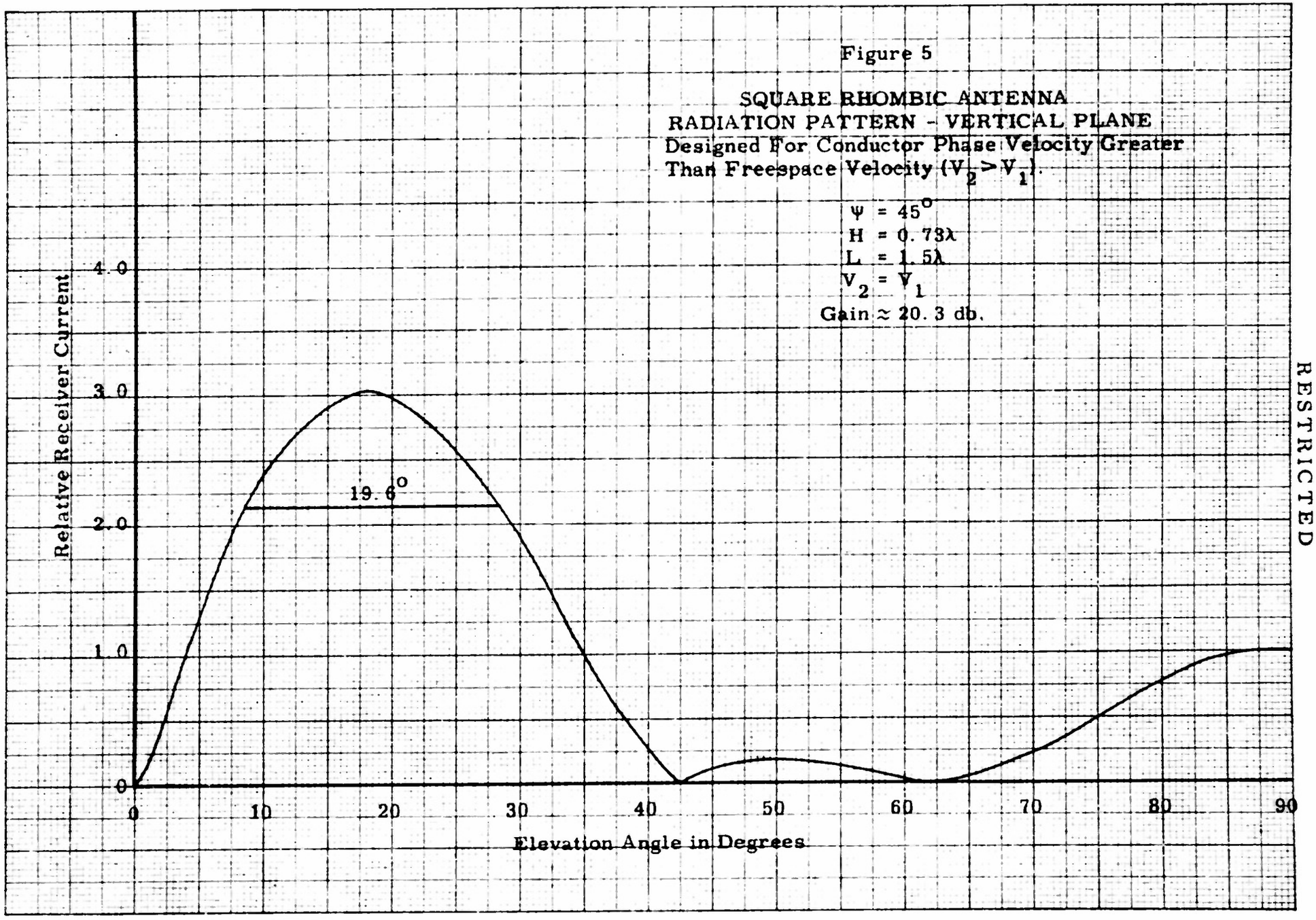

Figure 4

Radiation Angle Vs. Operating Frequency for Day, Jan. 1953

Figure 5

SQUARE RHOMBIC ANTENNA
RADIATION PATTERN - VERTICAL PLANE
Designed For Conductor Phase Velocity Greater Than Freespace Velocity ($V_2 > V_1$).

$\psi = 45^{\circ}$
$H = 0.73\lambda$
$L = 1.5\lambda$
$V_2 = V_1$
Gain $\approx$ 20.3 db.



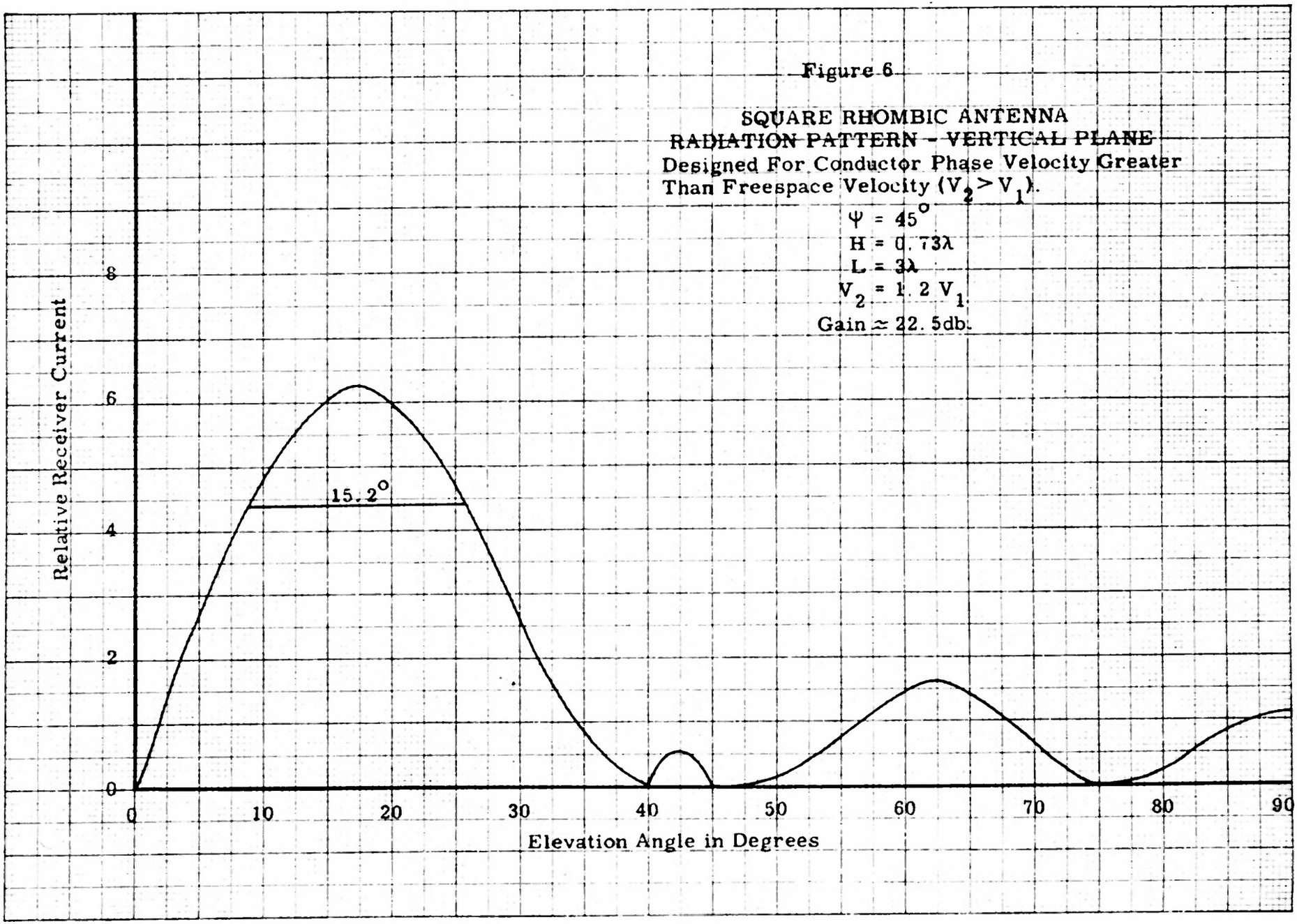


RESTRICTED

Figure 6

SQUARE RHOMBIC ANTENNA
RADIATION PATTERN - VERTICAL PLANE
Designed For Conductor Phase Velocity Greater Than Freespace Velocity ($V_2 > V_1$).

$\psi = 45^\circ$
$H = 0.73\lambda$
$L = 3\lambda$
$V_2 = 1.2\ V_1$
Gain $\approx$ 22.5db.



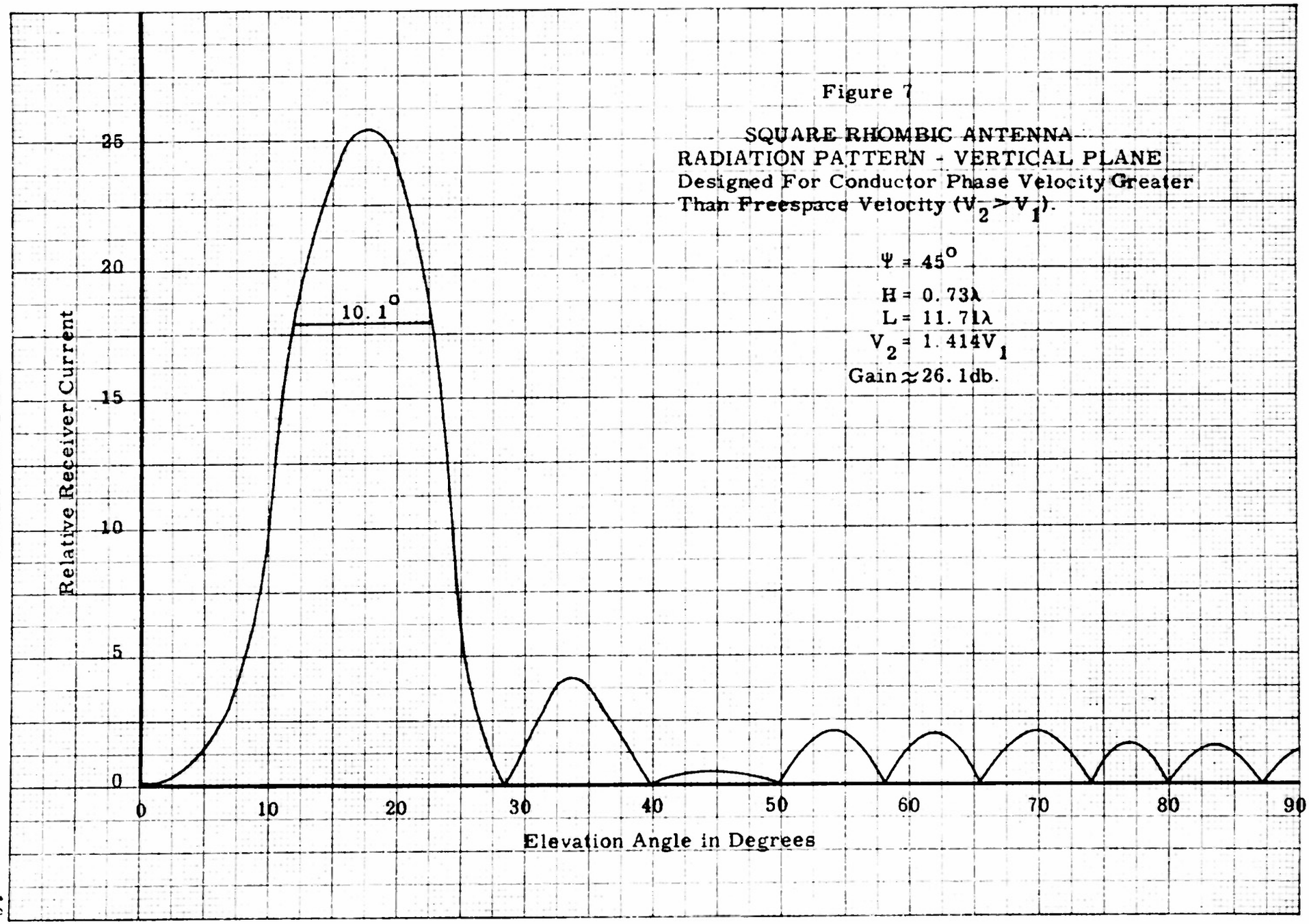



Figure 7

SQUARE RHOMBIC ANTENNA
RADIATION PATTERN - VERTICAL PLANE
Designed For Conductor Phase Velocity Greater Than Freespace Velocity ($V_2 > V_1$).

$\Psi = 45^\circ$

$H = 0.73\lambda$
$L = 11.71\lambda$
$V_2 = 1.414V_1$
Gain $\approx$ 26.1db.

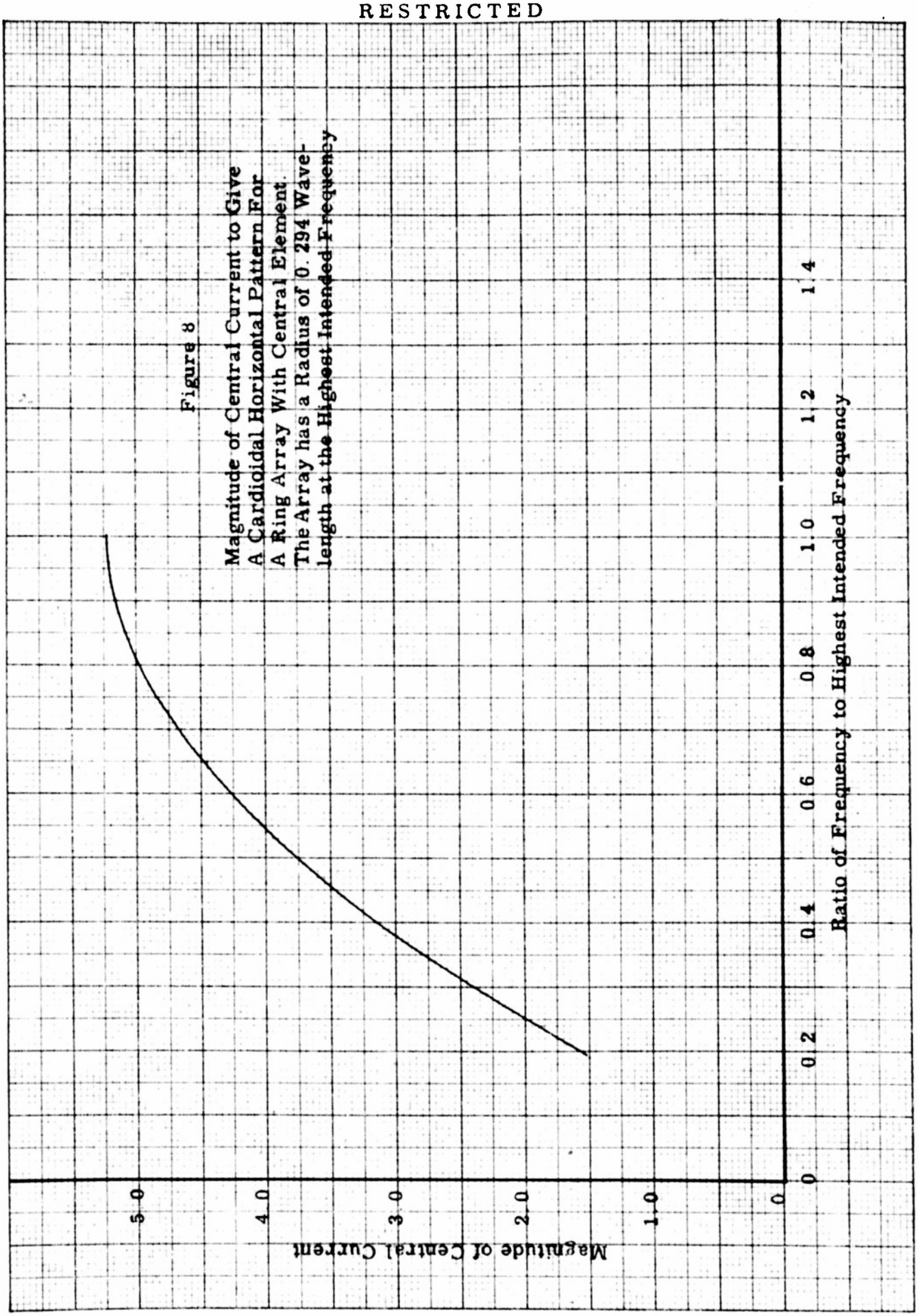



Figure 8

Magnitude of Central Current to Give A Cardioidal Horizontal Pattern For A Ring Array With Central Element. The Array has a Radius of 0.294 Wavelength at the Highest Intended Frequency

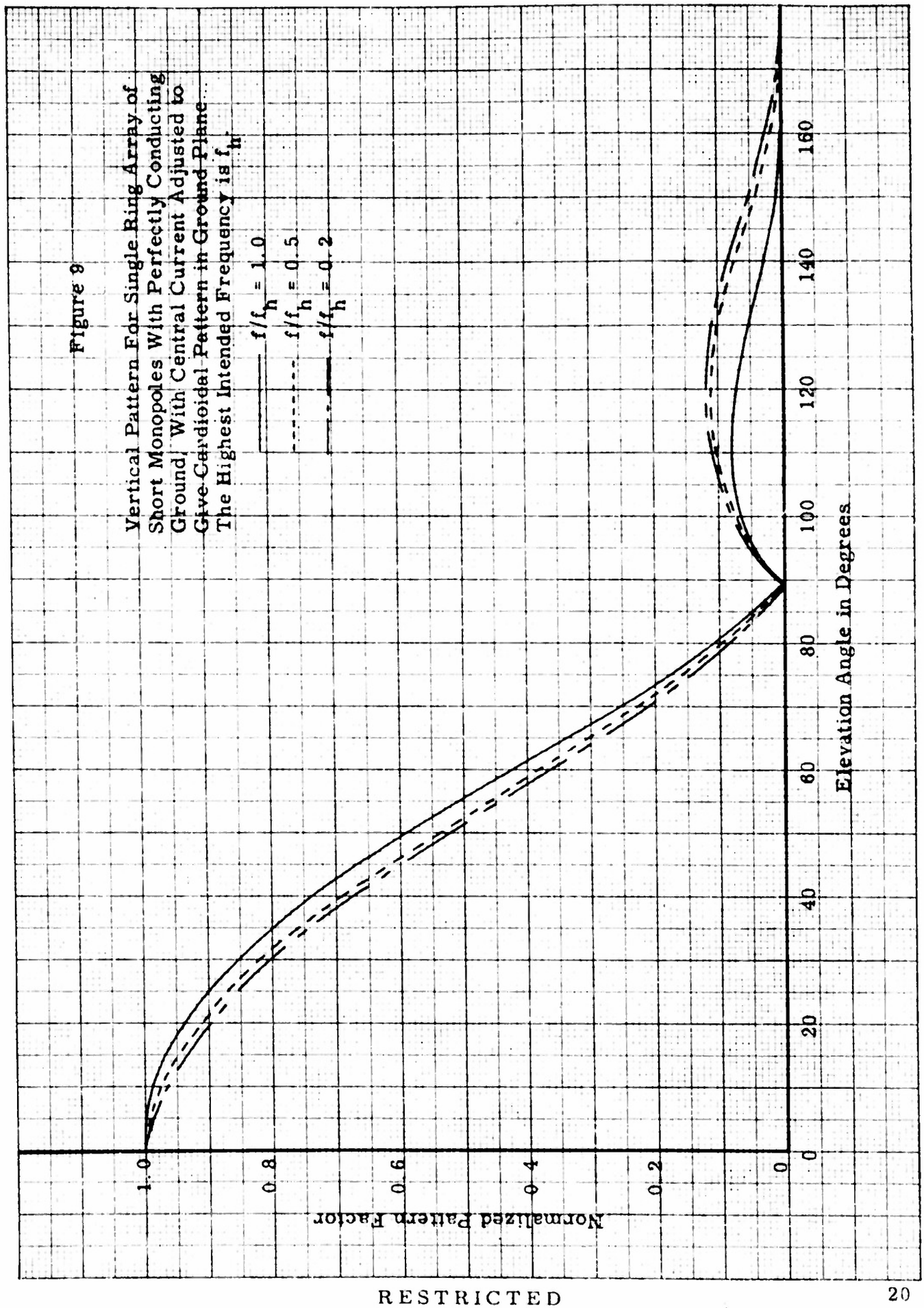



Figure 9

Vertical Pattern For Single Ring Array of Short Monopoles With Perfectly Conducting Ground With Central Current Adjusted to Give Cardioidal Pattern in Ground Plane. The Highest Intended Frequency is $f_h$.